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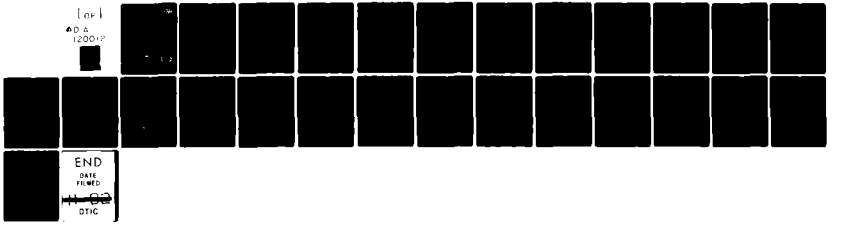

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SIMPLIFIED SOLAR FRACTION ESTIMATION FOR SPACE AND WATER HEATING AT DOD INSTALLATIONS

NELSON S. PACHECO, MAJOR, USAF
DANIEL G. KNIOLA, MAJOR, USAF
JAMES F. SHEEDY, CAPT, USAF
ROBERT J. SCARI, 2LT, USAF

SEPTEMBER 1982
FINAL REPORT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DEAN OF THE FACULTY
UNITED STATES AIR FORCE ACADEMY
COLORADO 80840

Technical Review by Capt Kehias
Department of Civil Engineering
USAF Academy, Colorado 80840

Technical Review by Capt Zelenok
Department of Civil Engineering
USAF Academy, Colorado 80840

Editorial Review by Capt Connally
Department of English
USAF Academy, Colorado 80840

This research report is presented as a competent treatment of the subject, worthy of publication. The United States Air Force Academy vouches for the quality of the research, without necessarily endorsing the opinions and conclusions of the author.

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This research report has been reviewed and is approved for publication.

THOMAS E. MCCANN, Lt Colonel, USAF
Director of Research and
Continuing Education

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report contains a set of nomographs which can be used to estimate the average annual solar fraction for solar space and water heating at a large number of DOD facilities. The solar fraction estimated from the nomograph is in close agreement with F-Chart 3.0 and allows for variation of the following parameters: annual load, collector area, collector transmittance-absorptance coefficient, and collector overall loss coefficient.

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SEPTEMBER 1982

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This research was sponsored by the Air Force Engineering Services Center (AFESC/DEB), Tyndall AFB, Florida under Project Order F81-66 .
The methods used herein are based on FCHART[1], the GFL method[2], and PASO[3] charts. The PASO chart method was developed by N. Pacheco and K. Soderstrom under the sponsorship of the Oak Ridge Associated Universities Summer Faculty Research Program at the Center for Energy and Environmental Research (CEER) of the University of Puerto Rico. All of the work in this report was conducted in the Department of Mathematical Sciences (DFMS), U.S. Air Force Academy, Colorado 80840.
Additionally consulting on this work were Captain David Murchison of the Academy's Mathematics Department and Captains George Kehias, Marcos Madrid, and David Zelenok of the Civil Engineering Department. Special thanks to Ms. Lynn Henderson and Miss Julie Neubert for their typing support.

(1) See Bibliography #1

(2) See Bibliography #7

(3) See Bibliography #11

INTRODUCTION

This report contains a set of four nomographs for each of a large number of Department of Defense (DOD) installations. These nomographs can be used to estimate the average annual solar fraction, or f-value, defined by:

$$f = \frac{\text{Annual Energy Demands Supplied by Solar Energy}}{\text{Total Annual Energy Demands}}$$

Thus the f-value can be directly interpreted as the fraction of annual energy requirements which can be met in a typical year by solar energy.

These nomographs provide a simplified method to estimate an annual f-value with a typical RMS accuracy of two percent from the popular FCHART method. However, unlike the FCHART method which requires twelve monthly calculations and conversion of insolation data from a horizontal plane to the collector plane, the use of these nomographs only requires knowledge of the annual load and the usual system design parameters $F_r U_l$ and $F_r \tau\alpha$. Furthermore, as a way of observing their effect on the solar fraction, the values of these parameters can be easily varied.

The included nomographs are to be used for preliminary design and for assessment of solar energy potential at the installations listed. They are not meant to replace detailed engineering design methodology used to guide the construction phase of solar installations. The solar fraction determined using these methods only has validity against a similar FCHART computation. The validity of FCHART against actual installations is a topic beyond the scope of this effort. However, existing studies [3], [4], have shown that FCHART correlates quite well with existing installations in those cases in which the actual designs match those for which FCHART was intended. In particular, the designs on which these nomographs are based are typical residential systems will be further discussed in section 2 of this report.

2. System Design

As in the FCHART method, the nomographs in this report are designed for residential solar space heating and solar water heating systems. The space heating system is assumed to supply both space and water heating. However, the water heating accounts for only a small portion (15-20%) of the space heating load. The water heating system supplies water heating entirely. A schematic of the system design is provided in Fig. 1. FCHART 3.0 provides for corrections which allow the designer to vary many design parameters. The most significant of these in practical terms are the collector heat removal - transmittance - absorptance factor($F_r\tau\alpha$), the collector heat removal - overall energy loss coefficient (F_rU_l), the collector area (A), and, of course, the load (L). These nomographs allow for the variation of these parameters over a very wide range. All other design parameters besides these are fixed at nominal values, listed in Table 1. Appendix A lists the location of the recording stations on which the insolation and temperature data was based. All of the data was based on Input Data For Solar Systems, Nov 1978.

Sensitivity Analysis

As with FCHART 3.0, these nomographs are valid for all 50-50 Ethylene Glycol-water systems following the basic design of Figure 1. The nominal desired water temperature was taken to be $140^{o}F$. However, water temperatures as high as $176^{o}F$ and as low as $104^{o}F$ were examined with no significant change in the annual solar fraction other than the over-riding effect of drastically different heating loads. The effect of local insolation and temperature values on system performance has been incorporated into the nomograph design

and need not be known to the user. In locations where the climate is fairly regular, the difference in f-value resulting from sophisticated differential-temperature controllers versus simple timers has been found to be negligible [10]. The chosen ground reflectance value of 0.2 is a low value typical of surfaces that do not reflect a significant amount of sunlight (clay, crushed rock, grass, etc.). If the area around the collectors is very bright, or is snow-covered for part of the year, slightly higher f-values can be expected ($\approx$3-5%). The collector azimuth or tilt can be varied as much as 15% with little effect. Similarly, the storage capacity can be varied between 1.25 and 2 gal/ft^2 with minimal effect. The load heat exchanger factor can be varied between 1 and 3. Values less than 1 (i.e., undersized heat exchangers) may cause an appreciable degradation of system performance. In tro ical locations where either a water - water system or else no collector heat exchanger is used, the water heating f-values may be up to three percent higher [11]. More detailed discussions of sensitivity analyses are contained in [1], [2], [3], [4], [6], and [9].

3. Sample Calculations

Appendices B and C contain a series of nomographs which allow the user to graphically find a good estimate of the yearly f-value. Each nomograph is site and system specific.

3a. Space Heating Example

For a space heating application, the user should refer to appendix B. To find the correct nomograph for the desired location the user should consult appendix

the location cross reference. The space heating nomographs are divided into low and high range sections. In the low range charts the lower end of the f scale, approximately 0.0-0.6, is expanded to allow more accurate readings at low f values. The low and high range charts for a given location will give the same results with the only difference being ease of reading. If the user anticipates a high f-value, he should attempt to use the high range chart, and then go to the low range charts if necessary.

Example Procedure for Low Range, Space Heating Nomograph

Given: A solar space heating system as described in Section 2 is located at Charleston AFB, South Carolina. Appendix A shows that for space heating, nomograph #87 is the appropriate one for Charleston AFB. The solution will be found on Space and Water Heating Nomograph #87, Low Range. Suppose that the total load on the system is 140 MBTU/YR, the collector area is 320 square feet, and Collector parameters are as follows:

$$F_r \tau\alpha = 0.80 \quad \text{(dimensionless)}$$

$$F_r U_l = 0.90 \quad \text{BTU/(HR)(FT}^2\text{)(}^\circ\text{F)}$$

Procedure: The annual solar fraction is found directly from nomograph #87 by the following steps:

(Figure 2 illustrates the procedure)

3a1. One enters the nomograph at the lower lefthand chart with area and load. Either the inner or outer scale may be used, but one may not use different scales for the two values. At the intersection of the vertical and horizontal lines drawn from these two points, follow the appropriate diagonal (which may have to be drawn in) up to the horizontal scale line.

3a2. From this point, continue vertically upward until intersecting with the diagonal line corresponding to the given $F_r\tau\alpha$, in this case 0.80. Then move horizontally to the right to the vertical scale. At this point, follow a path parallel to the diagonal dashed lines to the large "Yearly F Values" chart in the upper righthand section. Draw a horizontal line across that chart from the appropriate point on the lefthand vertical scale.

3a3. Now re-enter the nomograph in the lower righthand section. Using the given $F_r\tau\alpha$ and F_rU_1, in this case 0.80 and 0.90, draw a vertical and horizontal line from both of them until they intersect. From the point of intersection follow a path parallel to the diagonal lines to a point on the lower horizontal scale of the "Yearly F Values" chart. Draw a vertical line up from this point until it intersects with the horizontal line drawn in section 3a2.

3a4. At this point of intersection read off the f value. In this case it is approximately 0.47.

3b. Water Heating Example

For a water heating example, the user should again refer to appendix A to find the correct nomograph number. In this example we will use a high range nomograph.

Example Procedure for High Range, Water Heating Nomograph

Given: A solar water heating system as described in section 2.0 is located at Mather AFB, California. Appendix A shows that water heating nomograph #11 should be used. The total load of the system is 43 MBTU/YR and the collector area is 210 square feet. Collector parameters are as follows:

$$F_r\ \tau\alpha = 0.86 \text{ (dimensionless)}$$

$$F_r\ U_1 = 1.20\ BTU/(HR)(FT^2)(^oF)$$

Procedure: Water Heating, High Range Nomograph #11 is used, and the solution, .82, is found directly from it following the same steps as used in the space heating example. Figure 3 illustrates the procedure.

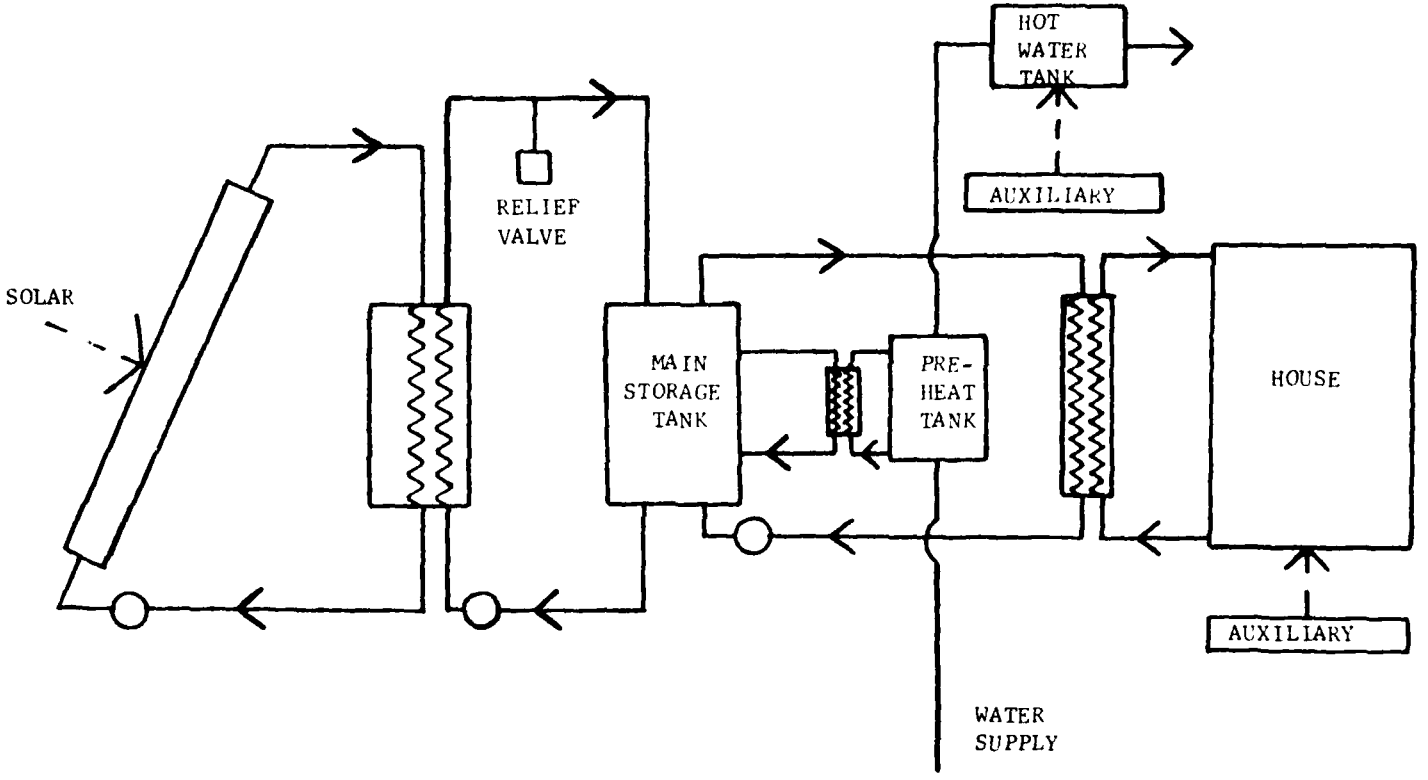

FIGURE 1 LIQUID-BASED SOLAR HEATING SYSTEM

FIGURE 2

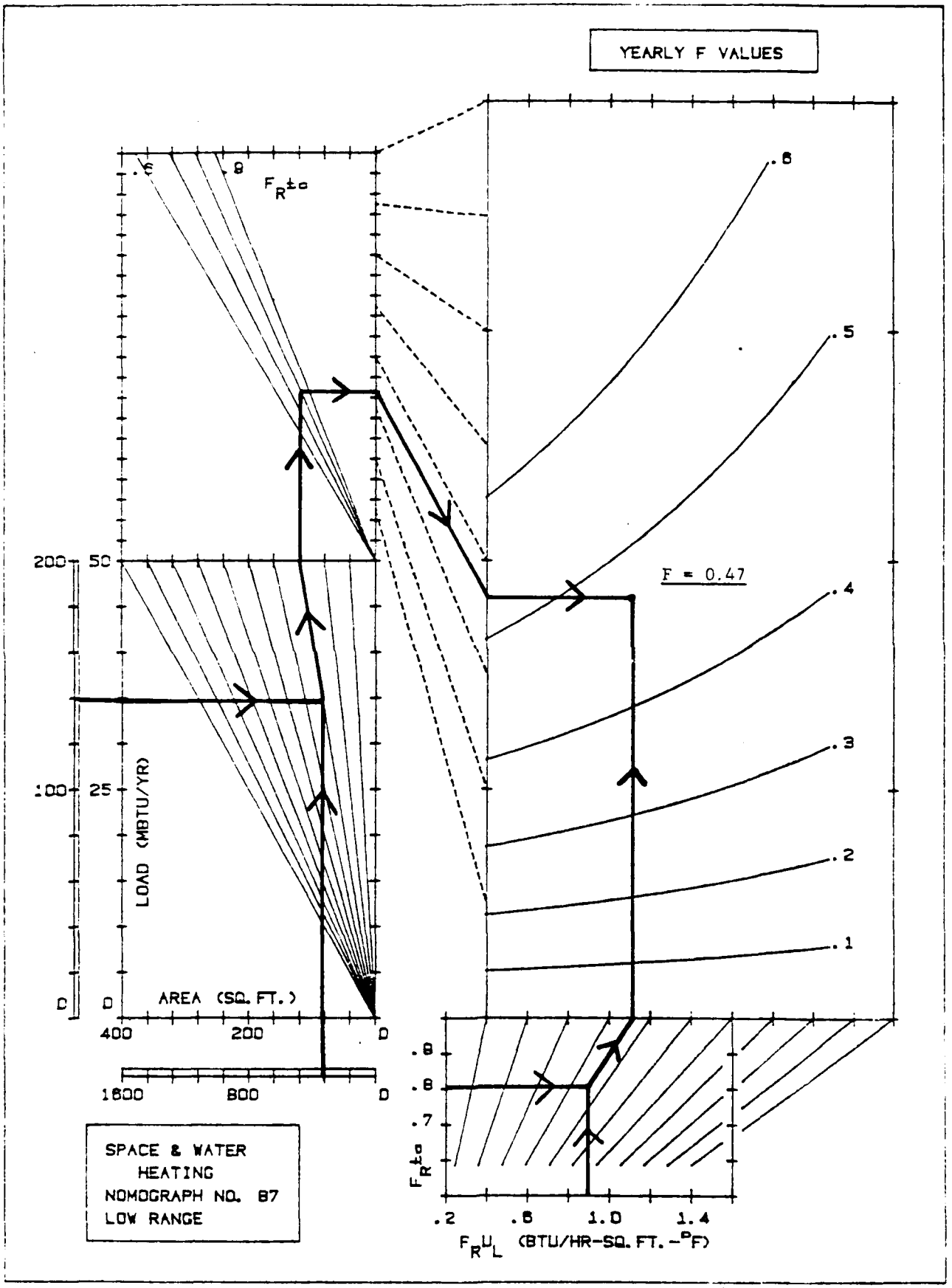

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FIGURE 3

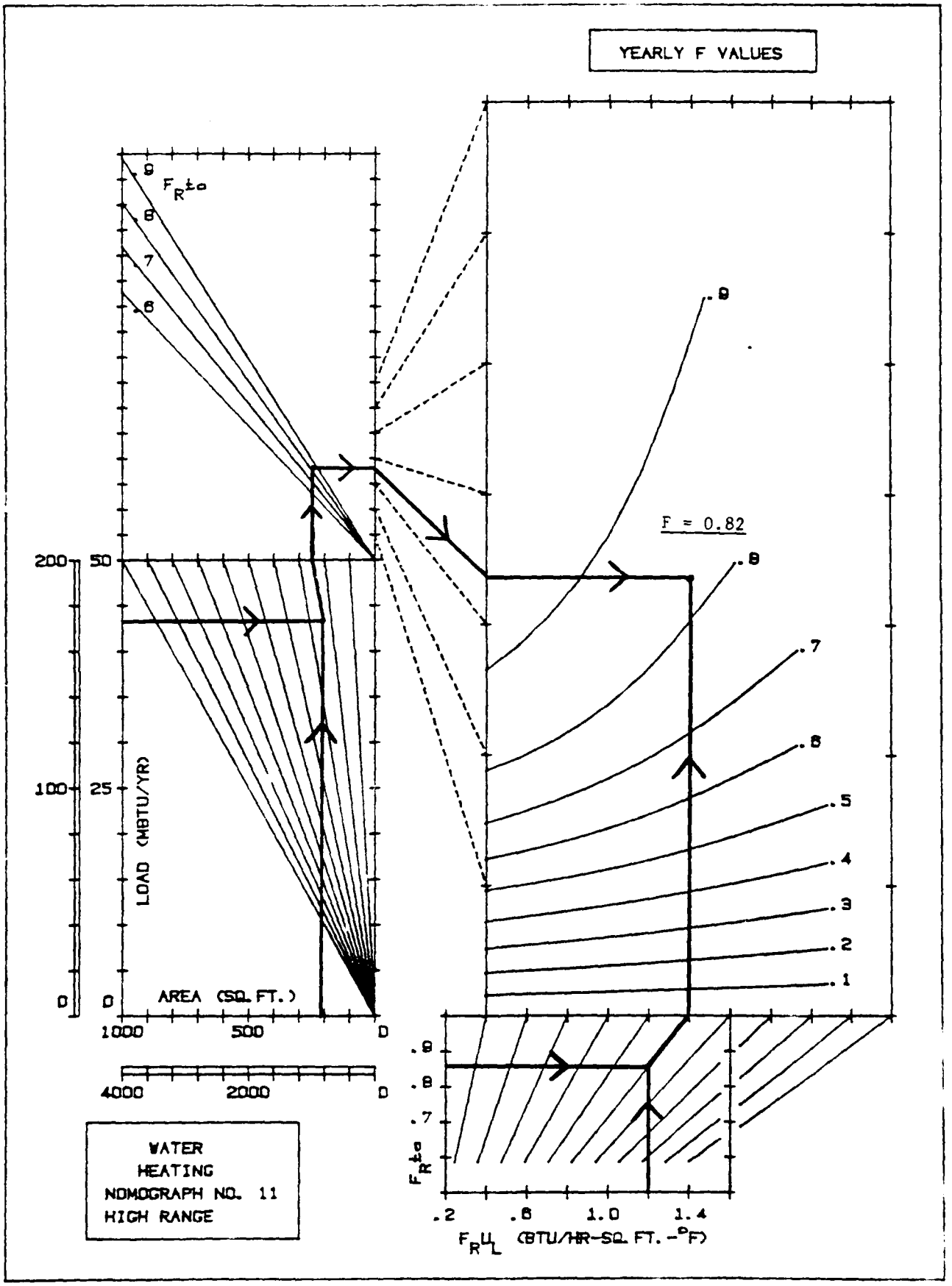

TABLE I - NOMINAL DESIGN PARAMETERS

Hot Water Temperature----------$140^{o}F$

Ground Reflectance----------0.2 (year-round)

Collector azimuth----------due South

Collector tilt----------equal to latitude

Storage Mass----------1.84 Gal/Sq Ft Collector area

Collector Flowrate----------0.022 GPM/Ft^2

Collector Fluid----------50-50 Ethylene Glycol-water

Load Heat Exchanger Factor---------ε_1 Cmin/UA = 2.0 (N/A for water heating)

Collector Heat Exchanger
Efficiency Factor----------0.9

Average $\tau\alpha$/Normal $\tau\alpha$----------0.97

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APPENDIX A - LOCATION - NOMOGRAPH CROSS REFERENCE LIST

LOCATION	NOMOGRAPH NUMBER SPACE	WATER	INSOLATION	TEMP
Alabama				
Anniston Army Depot	0	0	Birmingham, AL	Birmingham, AL
Coosa River	0	0	Birmingham, AL	Birmingham, AL
Ft. McLellan	0	0	Birmingham, AL	Birmingham, AL
Ft. Rucker	25	3	Tallahasee, FL	Tallahasee.FL
Mobile, AL	3	4	Mobile, AL	Mobile, AL
Phosphate Dev. Works	1	1	Memphis, TN	Memphis, TN
Redstone Arsenal	2	2	Chatanooga, TN	Chatanooga,TN
Arizona				
Davis-Montham AFB	125	122	Tucson,AZ	Tuscon,AZ
MCAS, Yuma	15	16	Yuma, AZ	Yuma, AZ
Navajo Depot Activity	4	5	Winslow, AZ	Winslow, AZ
NAVOBSYSTA	4	5	Winslow, AZ	Winslow,AZ
Luke AFB	122	119	Phoenix,AZ	Phoeniz,AZ
Williams AFB	122	119	Phoenix,AZ	Phoenix,AZ
Arkansas				
Blytheville AFB	1	1	Memphis, TN	Memphis,TN
Ft. Chaffee	5	6	Little Rock,AR	Little Rock,AR
Little Rock	5	6	Little Rock,AR	Little Rock,AR
Pine Bluff	5	6	Little Rock,AR	Little Rock,AR
California				
Beale AFB	10	11	Sacramento,CA	Sacramento,CA
Camp Parks	7	8	Oakland,CA	Oakland, CA
Camp Roberts	6	7	Santa Maria,CA	Santa Maria,CA
Castle AFB	10	11	Fresno,CA	Fresno,CA
Edwards AFB	14	15	Daggett,CA	Daggett,CA
Ft. Baker	7	8	S.F., CA	S.F., CA
Ft. Hunter Liggett	9	10	Sunnyvale,CA	Sunnyvale,CA
Ft. Irwin	14	15	Daggett, CA	LA., CA
Ft. MacArthur	11	12	Long Beach,CA	L.A., CA
Ft. Ord	9	10	Sunnyvale,CA	S.F., CA
George AFB	14	15	Daggett,CA	Daggett,CA
Letterman Army Med.Cent.	7	8	S.F., CA	S.F., CA
March AFB	11	12	Los Angeles,CA	Los Angeles,CA
Mather AFB	10	11	Sacramento,CA	Sacramento,CA
MCAGCC, 29 Palms	14	15	Daggett, CA	L.A., CA
MCAS El Tora, Santa Ana	11	12	Los Angeles, CA	Los Angeles, CA
MCAS(H) Tustin, CA	11	12	Los Angeles, CA	Los Angeles, CA
MCB Camp Pendleton	11	12	San Diego,CA	San Diego, CA
MCLB, Barstow	14	15	Daggett, CA	L.A., CA
McLellan AFB	10	11	Sacramento,CA	Sacramento, CA
MCRD, San Diego	11	12	San Diego, CA	San Diego, CA
NAF, El Centro	15	16	Yuma, AZ	Yuma, AZ
NAS Lemore	10	11	Fresno, CA	Fresno, CA

LOCATION	SPACE	WATER	INSOLATION	TEMP
California				
NAS, Moffett Field	9	10	Sunnyvale, CA	S.F., CA
NAS, Moramar, San Diego	11	12	San Diego, CA	San Diego, CA
NAVAIRREWORKFAC, Alameda	7	8	S.F., CA	S.F., CA
NAVCOMSTA Stockton	10	11	Sacramento, CA	Sacramento, CA
NAVFAC, San Nicholas Is.	11	12	Los Angeles, CA	Los Angeles, CA
NAVSECGRVACT Scaggs Is.	7	8	S.F., CA	S.F., CA
NAVSHIPYD, Long Beach	11	12	Long Beach, CA	L.A., CA
NAVSHIPYD Mare Is.	7	8	S.F., CA	S.F., CA
NAVSUPPACI, Treas. Is.	7	8	S.F., CA	S.F., CA
NAVWPNCEN, China Lake	14	15	Daggett, CA	Daggett, CA
NAVWPNSTA, Concord	7	8	S.F., CA	S.F., CA
Norton AFB	14	15	Daggett, CA	Daggett, CA
Oakland	7	8	Oakland, CA	Oakland, CA
PACMISTESCEN, Pt. Magu	11	12	Los Angeles, CA	Los Angeles, CA
Presidio of S.F.	7	8	S.F., CA	S.F., CA
Presidio, Monterey	9	10	Sunnyvale, CA	S.F., CA
PWC, San Diego	11	12	San Diego, CA	San Diego, CA
PWC, S.F.	7	8	Oakland, CA	Oakland, CA
River Bank Army Ammo	10	11	Fresno, CA	Fresno, CA
Sacramento Army Depot	10	11	Sacramento, CA	Sacramento, CA
Sharpe Army Depot	7	8	Oakland, CA	Oakland, CA
Sierra Army Depot	16	17	Reno, NV	Reno, NV
Travis AFB	7	8	Oakland, CA	Oakland, CA
Vandenburg AFB	6	7	Santa Maria, CA	Santa Maria, CA
WESTNAVFACENGCOM	7	8	S.F., CA	S.F., CA
WPNSTA, Seal Beach	11	12	Long Beach, CA	L.A., CA
Colorado				
Fitzsimmons	19	20	Denver, CO	Denver, CO
Ft. Carson	18	19	Colo. Spgs, CO	Colo.Spgs.,CO
Lowry AFB	19	20	Denver, CO	Denver, CO
Pueblo Army Depot	19	20	Pueblo, CO	Pueblo, CO
Rocky Mtn Arsenal	19	20	Denver, CO	Denver, CO
USAFA	18	19	Colo Spgs,CO	Colo Spgs,CO
Connecticut				
NAVNUPWRTRAU, Windsor	126	123	Hartford,CT	Hartford,CT
Stratford Army Engine Plant	72	71	NYC(Central Park)	NYC(Central Park)
Delaware				
Dover	127	124	Wilmington,DE	Wilmington,DE
NAVFAC Lewes, DE	127	124	Wilmington,DE	Wilmington,DE
Dist. of Columbia				
Army Top Sta	21	22	Wash, D.C.	Wash, D.C.
Bolling AFB	21	22	Wash, D.C.	Wash, D.C.
Ft. McNair	21	22	Wash, D.C.	Wash, D.C.
HQ NAVSPACEDIS	21	22	Wash, D.C.	Wash, D.C.
NAF Andrews AFB	21	22	Wash, D.C.	Wash, D.C.
NAVOBSY	21	22	Wash, D.C.	Wash, D.C.
Walter Reed Army Med	21	22	Wash, D.C.	Wash, D.C.

LOCATION	SPACE	WATER	INSOLATION	TEMP
Florida				
Eglin	22	23	Apalachicola,FL	Apalachicola,FL
Homestead	123	120	Miami,FL	Miami,FL
Hurlburt Field	22	23	Apalachicola,FL	Apalachicola,FL
MacDill	23	24	Tampa, FL	Tampa, FL
NAS Cecil Field	121	118	Jacksonville,FL	Jacksonville,FL
NAS Jacksonville	121	118	Jacksonville,FL	Jacksonville,FL
NAS Key West	N/A	120	Miami,FL	Miami,FL
NAS Whiting Field,Milton	22	23	Apalachicola,FL	Apalachicola,FL
NAVCOASTSYSCEN,Pam City	22	23	Apalachicola,FL	Apalachicola,FL
NAVSECGRUACT Homestead	N/A	120	Miami,FL	Miami,FL
NAVSTA Mayport	121	118	Jacksonville,FL	Jacksonville,FL
NTC Orlando	124	121	Orlando,FL	Orlando,FL
Patrick	124	121	Orlando,FL	Orlando,FL
PWC Pensacola	22	23	Apalachicola,FL	Apalachicola,FL
Tyndall	22	23	Apalachicola,FL	Apalachicola,FL
Georgia				
Dobbins AFB	24	25	Atlanta, GA	Atlanta, GA
D. Eisenhower AMC	26	26	Augusta, GA	Augusta, GA
Ft. Benning	26	26	Macon, GA	Macon, GA
Ft. Gillen	24	25	Atlanta, GA	Atlanta, GA
Ft. Gordon	26	26	Augusta, GA	Augusta, GA
Ft. McPherson	24	25	Atlanta, GA	Atlanta, GA
Ft. Stewart	26	26	Savannah,GA	Savannah, GA
Hunter Army Air Field	26	26	Savannah, GA	Savannah, GA
Moody	25	3	Tallahassee,FL	Tallahassee,FL
NCLB Albany	25	3	Tallahassee,FL	Tallahassee,FL
NAS Atlanta	24	25	Atlanta, GA	Atlanta, GA
NAVSCSCOL, Athens	24	25	Atlanta, GA	Atlanta, GA
NAVSUBSUPPBASE, Kings Bay	121	118	Jacksonville, FL	Jacksonville,FL
Hawaii				
Camp H.M.Smith, Oahu	N/A	29	Honolulu, HI	Honolulu, HI
Hickham AFB	N/A	29	Honolulu, HI	Honolulu, HI
MCAS KANEOHE Bay,Oahu	N/A	29	Honolulu, HI	Honolulu, HI
NAS Barbers Pt.	N/A	29	Barbers Pt, HI	Barbers Pt, HI
NAVCAMSEASTPAC, Whaiwa	N/A	29	Honolulu, HI	Honolulu, HI
PACMISRANFAC Barking Sands	N/A	29	Honolulu, HI	Honolulu, HI
Pearl Harbor	N/A	29	Honolulu, HI	Honolulu, HI
Pahakuloa Tng Area,Hilo	N/A	30	Hilo, HI	Hilo, HI
Schofield Barracks	N/A	29	Honolulu, HI	Honolulu, HI
Tripler AMC	N/A	29	Honolulu, HI	Honolulu, HI
Wheeler Army Air Field	N/A	29	Honolulu, HI	Honolulu, HI
Idaho				
Mt Home	128	125	Boise,ID	Boise,ID
NAVNUPWRTRAU Idaho Falls	33	33	Pocatello, ID	Pocatello, ID

LOCATION	SPACE	WATER	INSOLATION	TEMP
Illinois				
Chanute AFB	35	35	Moline,IL	Moline,IL
Darcon Amm Center	35	35	Moline, IL	Moline, IL
Ft. Sheridan	34	34	Chicago, IL	Chicago, IL
Scott AFB	53	52	St. Louis, MO	St. Louis, MO
St.Louis Area Support Cent.	53	52	St. Louis, MO	St. Louis, MO
PWC Great Lakes	34	34	Chicago,IL	Chicago,IL
Rock Island Arsenal	35	35	Moline,IL	Moline,IL
Savanna Army Depot	35	35	Moline,IL	Moline,IL
Scott AFB	53	52	St. Louis,MO	St. Louis, MO
St.Louis Area Support Cent.	53	52	St. Louis, MO	St. Louis,MO
Indiana				
Crane Army Ammo Activity	37	37	Indianapolis,IN	Indianapolis,IN
Ft. Harrison	37	37	Indianapolis,IN	Indianapolis,IN
Indiana Army Amm Plant	40	40	Louisville, KY	Louisville,KY
Jefferson Proving Ground	75	74	Cincinatti,OH	Cincinatti, OH
NAVAVIONICCEN, Indianapolis	37	37	Indianapolis, IN	Indianapolis, IN
NAVWPNSUPPCEN, Crane	40	40	Louisville,KY	Louisville, KY
Iowa				
Iowa Army Ammo Plant	32	32	Burlington,Iowa	Burlington, Iowa
Kansas				
Ft. Leavenworth	53	52	Kansas City, MO	Kansas City, MO
Ft. Riley	38	38	Topeka, KS	Topeka, KS
Kansas Army Ammo Plant	54	53	Springfield,MO	Springfield,MO
McConnell	39	39	Wichita, KS	Wichita, KS
Kentucky				
Bluegrass Depot	40	40	Lexington, KY	Lexington, KY
Ft. Campbell	90	89	Nashville, TN	Nashville, TN
Ft. Knox	40	40	Louisville, KY	Louisville, KY
Lexington-Bluegrass Depot	40	40	Louisville, KY	Louisville, KY
NAVORDSTA,Louisville	40	40	Louisville, KY	Louisville, KY
Louisianna				
England	42	42	Lake Charles,LA	Lake Charles,LA
Ft. Polk	42	42	Lake Charles, LA	Lake Charles,LA
Gulf Outport	43	43	New Orleans,LA	New Orleans,LA
Louisanna Army Amm Plant	42	42	Shreveport,LA	Shreveport,LA
NAS New Orleans	43	43	New Orleans, LA	New Orleans,LA
Maine				
NAS, Brunswich	48	47	Portland, ME	Portland, ME

LOCATION	SPACE	WATER	INSOLATION	TEMP
Maryland				
Aberdeen Proving Ground	21	22	Baltimore, MD	Baltimore,MD
Andrews	21	22	Wash, D.C.	Wash, D.C.
Electronics R&D Command	21	22	Wash, D.C.	Wash, D.C.
Ft. Detrick	21	22	Baltimore, MD	Baltimore, MD
Ft. Meade	21	22	Baltimore, MD	Baltimore, MD
Ft. Ritchie	21	22	Baltimore, MD	Baltimore, MD
Harry Diamond Lab	21	22	Wash, D.C.	Wash, D.C.
NAS Patuxent River	21	22	Wash, D.C.	Wash, D.C.
NATNAVMEDCEN Bethesda	21	22	Wash, D.C.	Wash, D.C.
NAVORDSTA Indian Head	21	22	Wash, D.C.	Wash, D.C.
Silver Hill Observatory	21	22	Wash, D.C.	Wash, D.C.
USNA, Annapolis	21	22	Baltimore, MD	Baltimore, MD
Massachusets				
Army Mat & Mech Center	45	45	Boston, MA	Boston, MA
Fort Devens	45	45	Boston, MA	Boston, MA
Hanscom Field	45	45	Boston, MA	Boston, MA
NAS, South Weimuth	45	45	Boston, MA	Boston, MA
Natick R&D Center	45	45	Boston, MA	Boston, MA
Westover AFB	70	69	Albany, NY	Albany, NY
Michigan				
Detroit Arsenal	50	49	Detroit, MI	Detroit, MI
K.I. Sawyer				
Michigan Army Missile Plnt	50	49	Detroit, MI	Detroit, MI
NAF Detroit,Mt Clements	50	49	Detroit, MI	Detroit, MI
Tarcom Support Activity	50	49	Detroit, MI	Detroit, MI
Wurtsmith	49	48	Alpena, MI	Alpena, MI
Minnesota				
Twin City Army Amm Plant	52	51	Minneapolis/St.Paul MN	Same
Mississippi				
CBC Gulfport	116	110	New Orleans, LA	New Orleans,LA
Columbus AFB	113	112	Columbus,MS	Columbus,MS
Keesler AFB	116	110	Jackson, MS	Jackson, MS
Mississippi Army Amm Plnt	116	110	New Orleans, LA	New Orleasn,LA
NAS Meridian	113	112	Columbus, MS	Columbus, MS
Oceanography Cmd,NSTL Sta.	116	110	New Orleans, LA	New Orleans, LA
Missouri				
Fort Leonard Wood	54	53	Springfield,MO	Springfield,MO
Gateway Army Amm Plant	53	52	St. Louis, MO	St. Louis, MO
Lake City Army Amm Plant	53	52	Kansas City, MO	Kansas City, MO
MARFINCEN, K.C.,MO	53	52	Kansas City, MO	Kansas City, MO
St.Louis Army Amm Plant	53	52	St. Louis, MO	St. Louis, Mo
Nebraska				
Offutt AFB	60	59	North Omaha,NE	North Omaha,NE
Nevada				
Hawthorne Army Amm Plant	69	68	Tonopah, NV	Tonopah, NV
NAS Fallon	16	17	Reno, NV	Reno, NV
Nellis AFB	68	67	Las Vegas, NV	Las Vegas, NV

LOCATION	SPACE	WATER	INSOLATION	TEMP
New Hampshire				
NSY Portsmouth	61	60	Concord, NH	Concord, NH
Pease AFB	61	60	Concord, NH	Concord, NH
New Jersey				
Ft. Dix	62	61	Lakehurst, NJ	Newark, NJ
Ft. Monmouth	62	61	Lakehurst, NJ	Newark, NJ
McGuire AFB	62	61	Lakehurst, NJ	Newark, NJ
NAVAIRPROPCEN, Trenton	62	61	Lakehurst, NJ	Newark, NJ
NAVAIRENGCEN, Lakehurst	62	61	Lakehurst, NJ	Newark, NJ
Picatinny Arsenal	62	61	Newark, NJ	Newark, NJ
WPNSTA EarleColtsneck,NJ	62	61	Lakehurst, NJ	Newark, NJ
New Mexico				
Cannon AFB	64	63	Tucumcari, NM	Tucumcari, NM
Ft. Wingate Depot	67	66	Zuni, NM	Zuni, NM
Holloman AFB	64	63	Truth or Conseq,NM	Truth or Conseq.,NM
Kirtland AFB	64	63	Albuquerque, NM	Albuquerque,NM
White Sands	64	63	Truth or Conseq,NM	Truth or Conseq,NM
New York				
Ft. Drum	71	70	Massena, NY	Massena, NY
Ft. Hamilton	72	71	NYC(Central Park)	NYC(Central Park)
Ft. Wadsworth	72	71	NYC(Central Park)	NYC(Central Park)
Griffis AFB	73	72	Syracuse, NY	Syracuse, NY
NAVNVPWRTRAV, Schen.	70	69	Albany, NY	Albany, NY
NAVSUPPACT, Brooklyn	72	71	NYC(Central Park)	NYC(Central Park)
Plattsburgh AFB	73	72	Syracuse, NY	Syracuse, NY
Seneca Army Depot	73	72	Syracuse, NY	Syracuse, NY
Waterville Arsenal	70	69	Albany, NY	Albany, NY
West Point	72	71	NYC(Central Park)	NYC(Central Park)
North Carolina				
Camp McCall	58	57	Raleigh-Durham,NC	Raleigh-Durham,NC
Ft. Bragg	58	57	Raliegh-Durham,NC	Raliegh-Durham,NC
MCAS Cherry Pt.	115	114	Cherry Pt, NC	Wilmington, NC
NAVAIRREWORKFAC Ch. Pt.	115	114	Cherry Pt, NC	Wilmington, NC
NAVFAC, Cape Hatteras	56	55	Cape Hatteras,NC	Cape Hatteras,NC
NAVREGMEDCEN, Camplejoune	115	114	Cherry Pt,NC	Wilmington, NC
NCB, Camp Lejoune	115	114	Cherry Pt,NC	Wilmington, NC
Pope AFB	58	57	Raleigh-Durham,NC	Raleigh-Durham,NC
Seymour-Johnson AFB	58	57	Raleigh-Durham,NC	Raleigh-Durham,NC
Sunny Pt. Mil Ocean Term.	115	114	Cherry Pt,NC	Wilmington, NC
Tar Heel Army Missile Pl.	56	55	Greensboro, NC	Greensboro, NC
North Dakota				
Grand Forks AFB	59	58	Fargo, ND	Fargo, ND
Ohio				
Def Constr Supply Center	77	76	Columbus, OH	Columbus, OH
NAVFINCEN Cleveland	76	75	Cleveland, OH	Cleveland, OH
Ravena Army Amm Plant	74	73	Akron, OH	Akron, OH
US Army Modification Cntr	36	36	Fort Wayne, IN	Fort Wayne, IN

LOCATION	SPACE	WATER	INSOLATION	TEMP
Oklahoma				
Altus AFB	78	77	Oklahoma City,OK	Oklahoma City, OK
Fort Sill	78	77	Oklahoma City,OK	Oklahoma City, OK
McAlester Army Amm Plant	79	78	Tulsa, OK	Oklahoma City, OK
Vance AFB	78	77	Oklahoma City, OK	Oklahoma City, OK
Oregon				
NAVFAC COOS Head,Charlstn	80	79	North Bend, OR	Eugene, OR
Umatilla Depot	81	80	Pendleton, OR	Pendleton, OR
Pennsylvania				
Carlisle Barracks	82	81	Harrisburgh,PA	Harrisburgh,PA
Catalog Data Activity	82	81	Harrisburgh,PA	Harrisburgh,PA
Defense Pers Supp Center	83	82	Philadelphia,PA	Philadelphia,PA
FLEMATSUPPO,Mechanisburgh	82	81	Harrisburgh,PA	Harrisburgh,PA
Fort Indiantown Gap	82	81	Harrisburgh, PA	Harrisburgh,PA
Franfurt Arsenal	83	82	Philadelphia,PA	Philadelphia,PA
Hayes Army Amm Plant	84	83	Pittsburgh, PA	Pittsburgh,PA
Letterkenny Army Depot	82	81	Harrisburgh,PA	Harrisburgh,PA
New Cumberland Army Depot	82	81	Harrisburgh,PA	Harrisburgh,PA
Oakdale Support Center	84	83	Pittsburgh,PA	Pittsburgh,PA
Philadelphia	83	82	Philadelphia,PA	Philadelphia,PA
Scranton Army Amm Plant	85	84	Scranton,PA	Scranton,PA
Tolbyhanna Army Depot	85	84	Scranton,PA	Scranton,PA
Rhode Island				
NATC Newport	86	85	Providence, RI	Providence, RI
South Carolina				
Charleston AFB	87	86	Charleston, SC	Charleston, SC
Fort Jackson	88	87	Columbia, SC	Columbia, SC
MCAS Beanford	87	86	Charleston, SC	Charleston, SC
Myrtle Beach AFB	87	86	Charleston, SC	Charleston, SC
NAVSHIPYD	87	86	Charleston, SC	Charleston, SC
Shaw AFB	88	87	Columbia, SC	Columbia, SC
South Atlantic Outport	87	86	Charleston, SC	Charleston, SC
South NAVFACENGCON	87	86	Charleston, SC	Charleston, SC
WPNSTA Charleston	87	86	Charleston, SC	Charleston, SC
Tennessee				
Arnold AFS	90	89	Nashville, TN	Nashville, TN
Holston Army Amm Plant	2	2	Knoxville, TN	Knoxville, TN
Memphis Defense Depot	1	1	Memphis, TN	Memphis, TN
Milan Army Amm Plant	90	89	Nashville, TN	Nashville, TN
NAS Memphis,Millington	1	1	Memphis, TN	Memphis, TN
Volunteer Army Amm Plant	2	2	Chatanooga, TN	Chatanooga, TN
Texas				
Bergstrom AFB	92	91	Austin, TX	Austin, TX
Brooke AMC	92	91	San Antonio, TX	San Antonio, TX
Brooks AFB	92	91	San Antonio, TX	San Antonio, TX
Camp Ballis	92	91	San Antonio, TX	San Antonio, TX
Camp Stanley Atorage Act	92	91	San Antonio, TX	San Antonio, TX

LOCATION	SPACE	WATER	INSOLATION	TEMP
Texas(cont)				
Carswell AFB	94	93	Ft. Worth, TX	Ft. Worth, TX
Corpus Christi Army Depot	93	92	Corpus Christi, TX	Corpus Christi, TX
Dyess AFB	91	90	Abilene, TX	Abilene, TX
Ft. Bliss	96	95	El Paso, TX	El Paso, TX
Ft. Hood	94	93	Waco, TX	Waco, TX
Ft. Sam Houston	92	91	San Antonio, TX	San Antonio, TX
Kelly AFB	92	91	San Antonio, TX	San Antonio, TX
Lackland AFB	92	91	San Antonio, TX	San Antonio, TX
Laughlin AFB	91	90	Del Rio, TX	Del Rio, TX
Lone Star Army Amm Plant	42	42	Shreveport, LA	Shreveport, LA
Longhorn Army Amm Plant	42	42	Shreveport, LA	Shreveport, LA
NAS Chase Field,Beeville	93	92	Corpus Christi,TX	Corpus Christi, TX
NAS Corpus Christi	93	92	Corpus Christi,TX	Corpus Christi, TX
NAS Dallas	94	93	Dallas, TX	Dallas, TX
NAS Kingsville	93	92	Kingsville, TX	Kingsville, TX
Red River Army Depot	42	42	Shreveport, LA	Shreveport, LA
Reese AFB	99	98	Lubbock, TX	Lubbock, TX
Saginaw Army Acft Plant	94	93	Ft. Worth, TX	Ft. Worth, TX
Sheppard AFB	92	91	Wichita Falls, TX	Wichita Falls, TX
Wm.Beaumont Army Med.Ctr.	96	95	El Paso, TX	El Paso, TX
Utah				
Dugway Proving Gnd	103	102	Salt Lake City,UT	Salt Lake City,UT
Hill AFB	103	102	Sale Lake City,UT	Salt Lake City,UT
Ogden Def Depot	103	102	Salt Lake City,UT	Salt Lake City,UT
Toole Army Depot	103	102	Salt Lake City,UT	Salt Lake City,UT
Virginia				
Arlington Hall Station	21	22	Wash, D.C.	Wash, D.C.
Cameron Station	21	22	Wash, D.C.	Wash, D.C.
Def.General Supply Ctr	105	104	Richmond, VA	Richmond, VA
Ft. Belvoir	21	22	Wash, D.C.	Wash, D.C.
Ft. Eustis	104	103	Norfolk, VA	Norfolk, VA
Ft. Hill	105	104	Richmond, VA	Richmond,VA
Ft. Lee	105	104	Richmond, VA	Richmond, VA
Ft. Monroe	104	103	Norfolk, VA	Norfolk, VA
Ft. Meyer	21	22	Wash, D.C.	Wash, D.C.
Ft. Pickett	105	104	Richmond, VA	Richmond, VA
Ft. Story	104	103	Norfolk, VA	Norfolk, VA
HQMC Arlington,VA	21	22	Wash, D.C.	Wash, D.C.
Langley AFB	104	103	Norfolk, VA	Norfolk, VA
MCAS, Quantico, VA	21	22	Wash, D.C.	Wash, D.C.
Norfolk	104	103	Norfolk, VA	Norfolk, VA
Radford Army Amm Plant	106	105	Roanoke, VA	Roanoke, VA
Vint Hills Farm Sta.	21	22	Wash, D.C.	Wash, D.C.

LOCATION	SPACE	WATER	INSOLATION	TEMP
Washington				
Fairchild AFB	108	107	Spokane, WA	Spokane, WA
HQ 13th NAV District	107	106	Seattle, WA	Seattle, WA
McChord AFB	107	106	Seattle-Tacoma,WA	Seattle-Tacoma,WA
NAS Whidbey Island	108	107	Whidbey Isl,WA	Whidbey Isl.,WA
Navl Und.Sea Warfar.Eng.St	107	106	Seattle, WA	Seattle, WA
NAVSUBBASE Bangor WA	107	106	Seattle, WA	Seattle, WA
NRMC, Bremerton	107	106	Seattle, WA	Seattle, WA
West Virginia				
NAVRADSTA Sugargrove	106	105	Roanoke, VA	Roanoke, VA
Wisconsin				
Ft. McCoy	110	109	LaCrosse, WI	LaCrosse, WI